Cable Carrier Telephone Terminals *

By R. W. CHESNUT, L. M. ILGENFRITZ and A. KENNER

This paper describes the circuits, performance and equipment features of the terminals of a new 12-channel carrier system for application to existing toll cables. The 12-channel group of terminal apparatus has been designed also to form a basic part of the terminals of other carrier systems now under development, such as the type J system for open wire and the coaxial system.

Introduction

ABOUT twenty years ago the first commercial carrier telephone system was installed between Baltimore and Pittsburgh. Until recently, telephone circuits were obtained by carrier methods largely on open-wire lines. The notable exceptions were on short deep sea submarine cables.[1, 2] Ten years ago, experiments were initiated which have now resulted in the design of a carrier system which can be applied with substantial economy to existing long distance toll cables on land. Its general features are described in another paper.[3] The present paper describes in detail the circuits and performance of the carrier terminals of this system.

General Features

The carrier system for existing cables, designated type "K," is designed to provide twelve telephone channels in the frequency range between 12 and 60 kilocycles, using one non-loaded 19-gauge paper insulated cable pair in each direction. Previous carrier systems employed for open-wire lines used vacuum tubes for the modulating or translating circuits and electrical filters composed of coil and condenser networks for separating the frequency bands associated with the respective channels. The terminals of the new type "K" system are simpler and yet provide improved performance by using copper oxide bridges for the modulation function and quartz crystal filters [4] for the separation of the individual channel bands.

The quartz crystal filter is economical only in a comparatively high-frequency range, necessitating the use of high intermediate frequencies. The high intermediate frequencies are reduced by a second stage of modulation to the desired range of frequencies for transmission over the

* Presented at Winter Convention of A. I. E. E., Jan. 24–28, 1938.

line. Copper oxide bridge circuits again are used for this group modulation stage. In all cases they are connected to suppress the carrier. To provide the various carriers required for modulation and demodulation, a carrier supply system has been designed somewhat along the lines of an office power distribution system using bus bars and protective arrangements for the various carriers. Each carrier supply system is capable of supplying as many as ten carrier terminals, or a total of one hundred and twenty two-way channels.

Because of the large number of circuits involved, every effort has been made to provide reliable operation of the carrier supply and common terminal equipment. The terminal and carrier supply equipment is designed to permit maintenance tests for checking the performance of amplifier tubes and to permit switching between regular and spare equipment without interruption of the large number of circuits involved.

The emphasis placed upon ease of maintenance and the necessity for more careful handling of higher-frequency circuits have resulted in new equipment design features. These include new cable terminals, new shielded office cabling, and panels arranged for front wiring and maintenance which are mounted on racks having wiring ducts at both edges of the bays. In the following sections a more detailed description is given of the circuits, their performance, equipment and maintenance features.

Circuits

The frequency allocation for one direction of transmission and a block schematic of one terminal are shown in Figs. 1 and 2, which supplement each other and need little explanation. The twelve voice bands shown at the left in Fig. 1 are modulated individually in the channel modems.* This forms a 12-channel block lying between 60 and 108 kc. which is then modulated in the group modulator by a 120 kc. carrier to move the block down in the range from 12 to 60 kc. for transmission to the distant terminal. On the receiving side the processes are reversed. One of the channels, as well as the group modem of Fig. 2, is presented in more circuit detail in Fig. 3. This shows the circuit from the point where the voice comes into the carrier system to the point where the twelve carrier sidebands go out onto the cable and vice versa.

At the left the four-wire terminating circuit serves, not only as a device to transform from a two-wire to a four-wire circuit, but also as a

* The term "modem" has been coined to mean a panel or equipment unit in which there is both a modulator and a demodulator to take care of both the outgoing and the incoming signal.

high-pass filter to eliminate, from the input to the carrier system, noises below about 200 cycles, such as telegraph harmonics, 20-cycle ringing, 60-cycle power, etc., which may be present on connected voice-frequency circuits. Otherwise these noise frequencies, which are below the voice range, would modulate and pass through the terminal to load unnecessarily the carrier repeaters along the line, as well as to interfere with the level indications of the pilot channels.

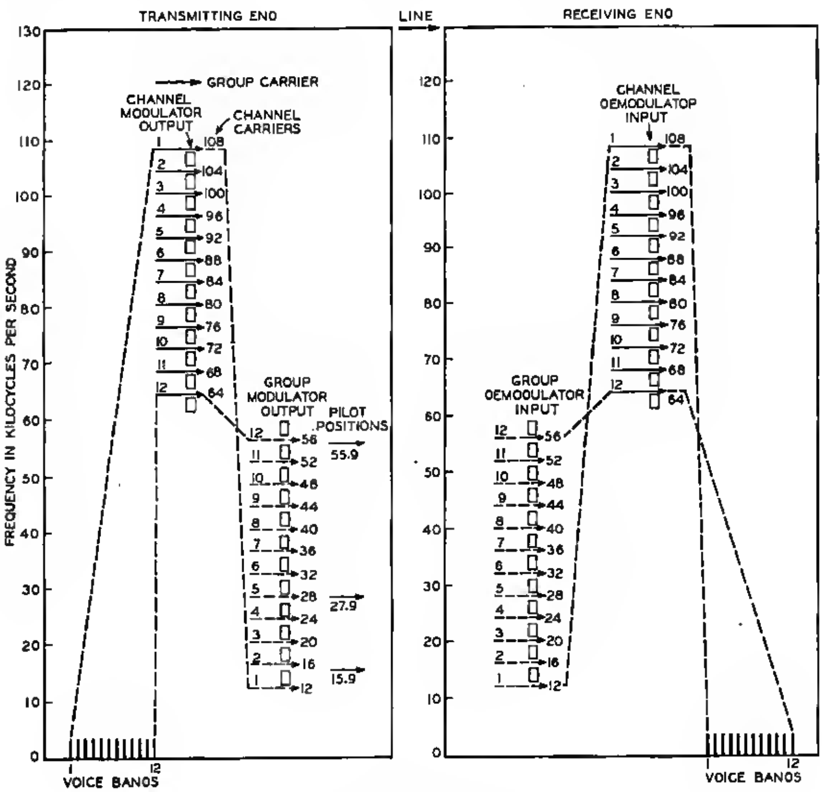

Fig. 1—Frequency allocation.

From the terminating equipment the circuit loops through jacks which have paralleled contacts for reliability. The level at this point is − 13 db compared with the transmitting toll switchboard, which level is expected to be generally used in the Bell System for all multi-channel carrier telephone systems. Then comes the channel modulator which consists of four copper-oxide discs, each three-sixteenths of an inch in diameter, potted in a small can. This makes a very simple and inexpensive modulator which is much more satisfactory than tubes.

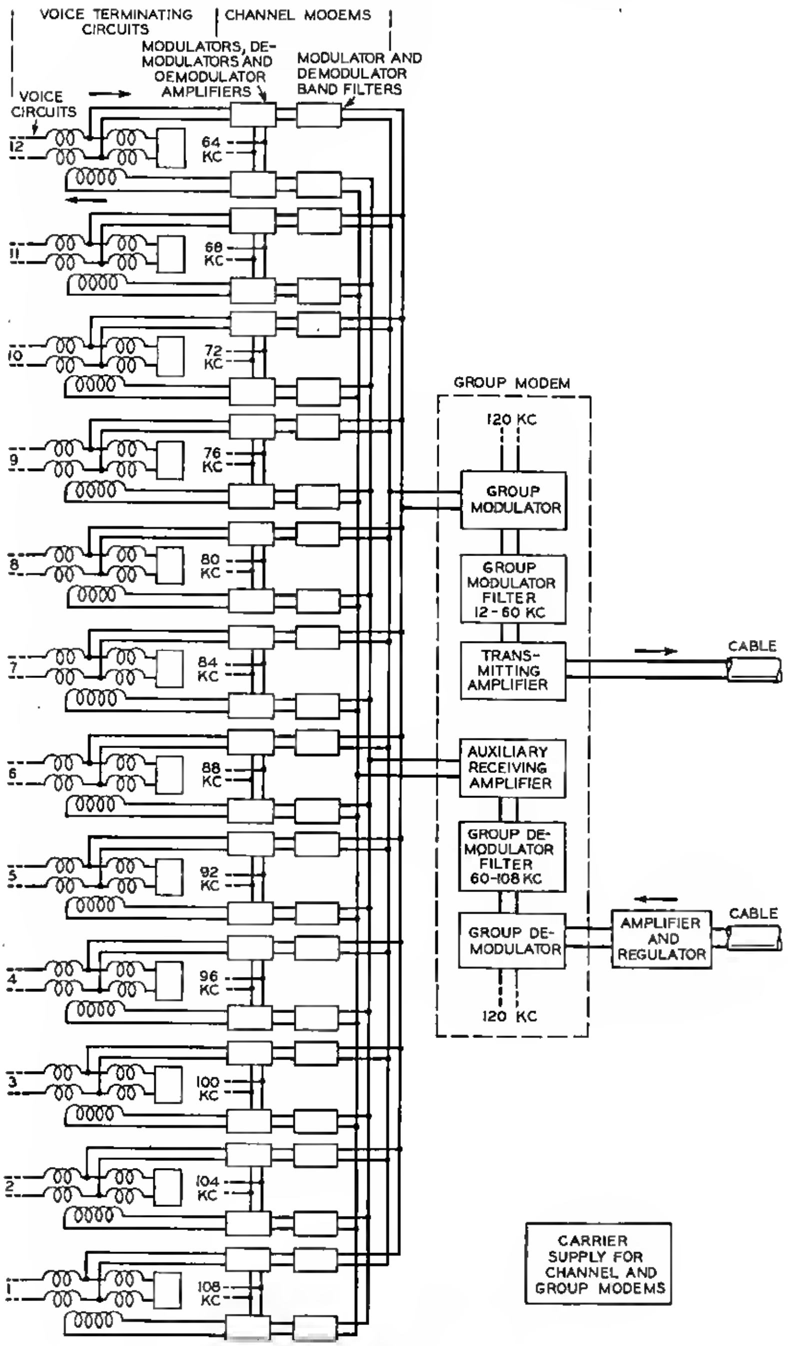

Fig. 2—Block schematic.

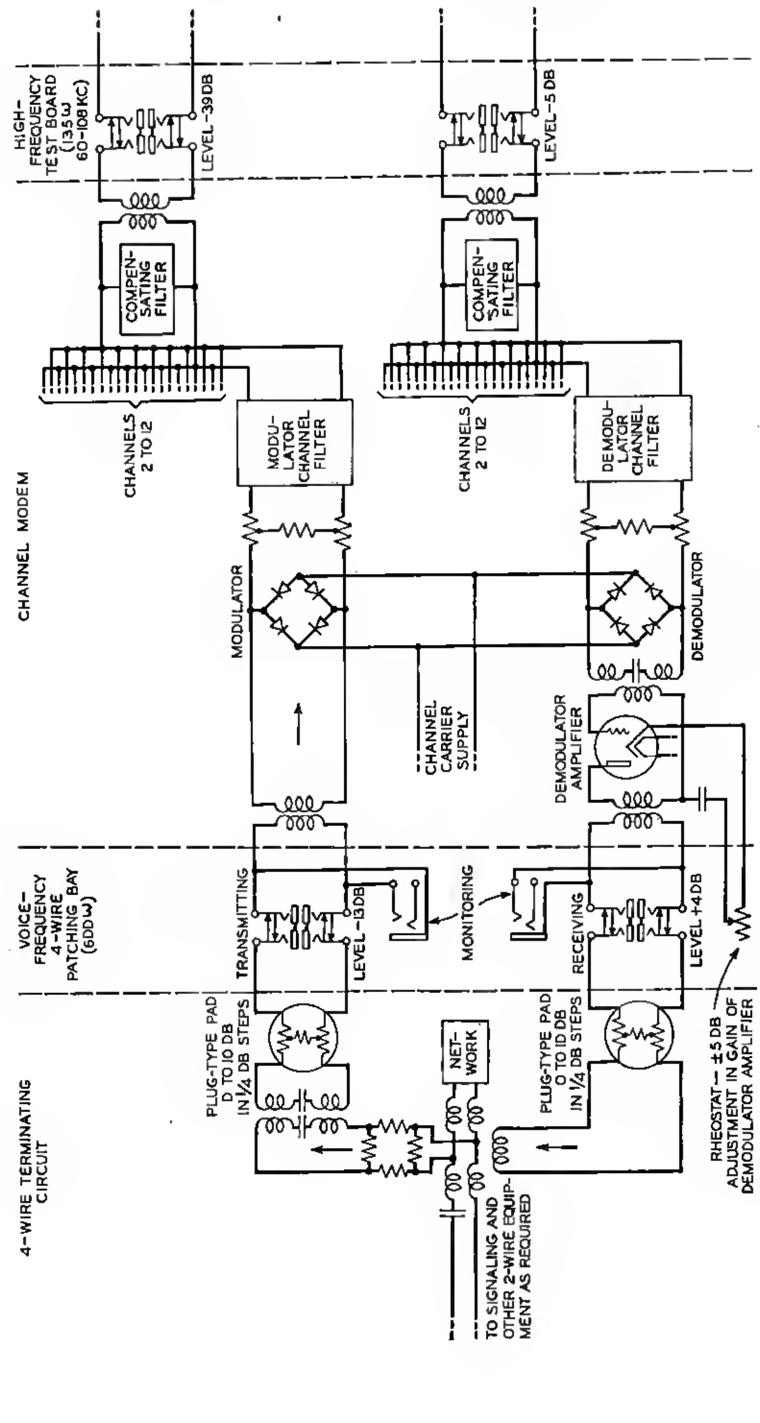

Fig. 3—Circuit schematic.

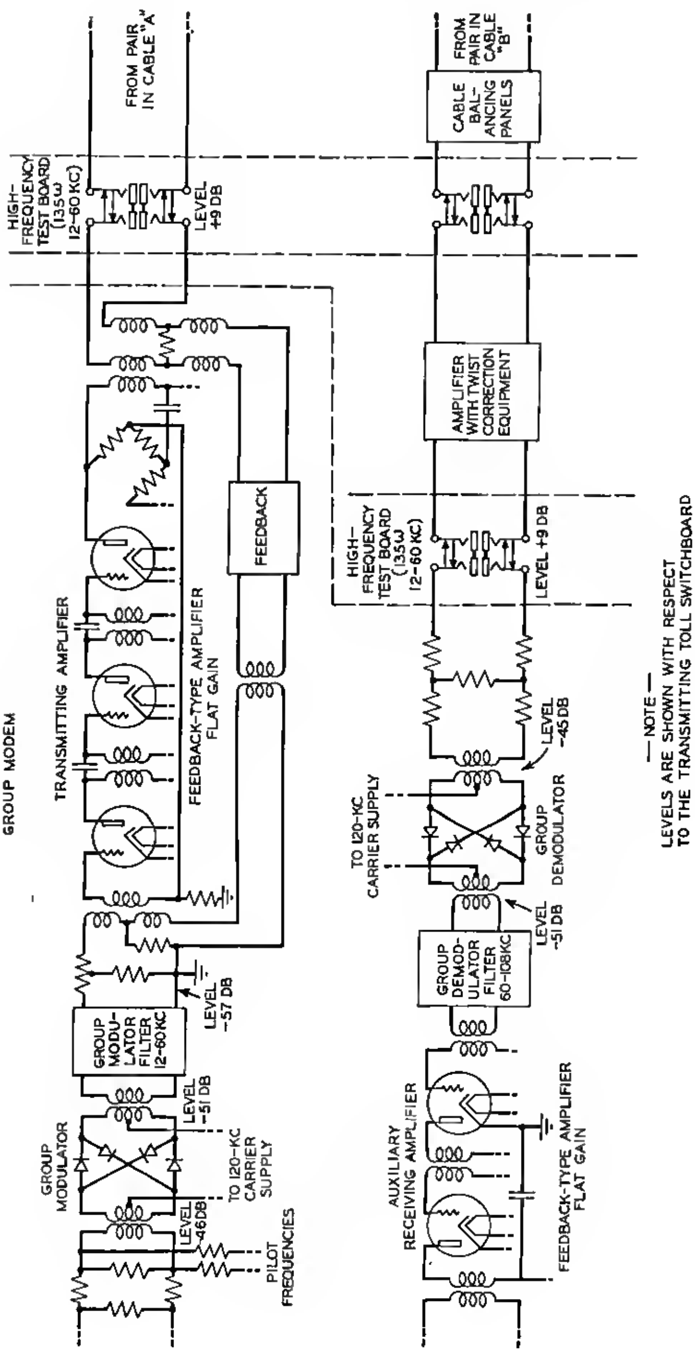

Fig. 3—*Continued from page 110.*

It seems to have an indefinite life. (Some have been on life tests as modulators for about five years.) The carrier power required is about 1/2 milliwatt to modulate satisfactorily a single telephone circuit level of − 13 db.

The modulator produces the usual two sidebands and the lower one is selected by the quartz crystal channel filter described in another paper.[4] This sideband, joined by eleven others, is stepped down to about the iterative impedance of the shielded office cabling. In the office cabling the twelve channels pass through the high-frequency patching bay to the double balanced group modulator of copper oxide where they are joined by three pilot channel frequencies.

The group modulator uses the same copper oxide as that in the channel modulator described above, but the carrier power is about 50 times greater (about 25 milliwatts) in order to keep down unwanted modulation produced between the twelve sidebands. To that same end the level of each sideband is made low (− 46 db), and the double balanced type of circuit is used to balance out some of the undesired products. It also balances out the twelve incoming bands in the range 60 to 108 kc. from the output and so simplifies the following group modulator filter.

From a level of − 57 db the twelve channels, now in the range from 12 to 60 kc., are amplified to + 9 db for delivery to the 19-gauge pair in the lead covered toll cable. The amplifier is a three-tube negative feedback type, using pentodes and operating with 154 volts plate battery which is composed of the usual 24-volt filament battery and 130-volt plate battery in series. The last tube is a power tube and does not overload until a single-frequency output of about one watt is reached.

On the receiving side in Fig. 3, the twelve incoming channels, in the range from 12 to 60 kc., pass from the amplifying and regulating equipment,[3] to the group demodulator. This is identical with the group modulator described above and transfers the twelve channels to the range 60 to 108 kc. The channels are then amplified to a − 5 db level by an amplifier of the negative feedback type using two low-power pentodes with 154-volt plate battery as described above for the transmitting amplifier.

From there the twelve channels are separated by the filters which are identical with those on the transmitting side, and are then demodulated and amplified to a + 4 db level as shown for one channel in Fig. 3. The demodulator is identical with the modulator but it is poled oppositely on the carrier supply so that the d-c. components of modulation in the modulator and demodulator neutralize each other

and thereby avoid developing an undesirable voltage bias. The poling also reduces somewhat the amount by which stray frequencies have to be suppressed in the carrier supply. The demodulator amplifier has a slide wire gain control rheostat to equalize channel levels, which functions by changing both the grid bias on the tube and the amount of negative feedback which is introduced by the rheostat. The sliding contact in the slide wire is made practically free from contact trouble by the space current of the tube flowing through it. As the rheostats are only about 1000 ohms and small in size, they can easily be mounted at a distance from the amplifier in the voice-frequency jack field.

The carrier supply for the twelve channels from 64 to 108 kc., and for the group modems of 120 kc., is derived in the circuit shown in Fig. 4. A regular generator is shown at the top in solid lines and an emergency generator at the bottom is shown in dotted lines. Between the two is an automatic transfer circuit (in dotted lines) which transfers to the emergency whenever the regular generator fails to supply the proper amount of 120 kc. to the 120 kc. bus.

At the upper left-hand corner is shown a 4-kc. tuning fork, of an alloy having a low temperature coefficient driven by the tube to its right to operate as an oscillator of very stable frequency. The next, or control tube, amplifies the 4 kc. to drive the push-pull power stage where a power of about 4 watts is developed. This passes through the 4 kc. filter to the non-linear coil where odd harmonics of 4 kc. are produced. The underlying principles of operation of this coil have been published.[5] To derive even harmonics of 4 kc., the copper-oxide bridge is used which rectifies about half the energy of the complex wave of odd harmonics but, by balance, greatly reduces the amount of the odd harmonics present in its output. Odd harmonics are obtained at one point and even at the other. This separation into odd and even harmonics by the balance of the copper-oxide bridge provides effective loss of about 30 to 40 db and reduces the requirements on the carrier supply filters which follow.

The two branches pass through hybrid coils to the banks of channel carrier supply filters. These separate the frequencies and feed them to twelve carrier supply bus bars, one for each channel frequency. From these the individual modems are fed through protective resistances so that an accidental short circuit on one of the modems will not cut off the carrier supply to the others.

The hybrid coils permit the two generators to be connected so that either can feed into the same bank of channel carrier supply filters without being reacted upon by the other. No switching is required when changing from regular to emergency supply.

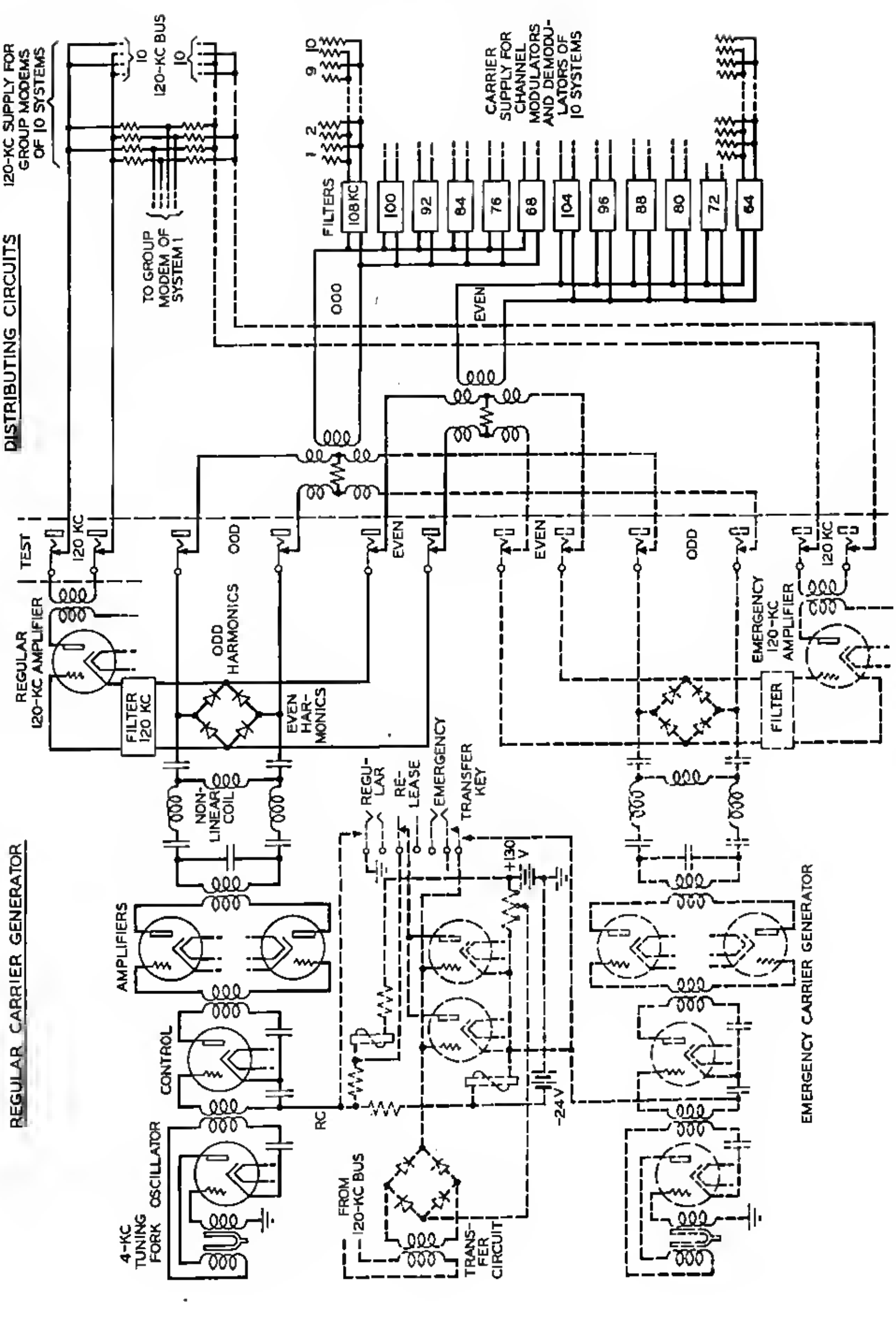

Fig. 4—Carrier supply circuit.

The 120-kc. carrier which feeds the group modulators of ten systems or a total of one hundred and twenty talking channels must be very dependable. Therefore separate filters are used for the regular and emergency supply and separate amplifiers for the large power required by group modulators. Regular and emergency distributing buses are provided. Each group modulator and each group demodulator is wired through protective resistances to the regular bus and through another set of protective resistances to the emergency bus. With this arrangement an accidental short circuit even across one of the busses or across one of the output coils of one of the 120-kc. amplifiers will not stop the whole supply of 120 kilocycles.

The 4-kc. oscillator of the emergency generator is in constant operation so that when it is needed no time is required to start it, but the grid bias on the second tube is held above its cutoff value by the automatic transfer circuit. This prevents the 4 kc. from going further until called for in an emergency.

An emergency is indicated when there is no 120-kc. supply on either the regular or emergency bus. When this happens, the copper-oxide rectifier in the transfer circuit gets no 120 kc. and so loses its rectified voltage. This triggers off one or both of the two gas-filled tubes (multipled for safety) which increases the grid bias on the control tube of the regular generator to stop its 4 kc. supply and at the same instant restores the bias to normal on the control tube of the emergency to let its 4 kc. pass through and put the whole emergency circuit into operation. The keys in the transfer circuit are provided for maintenance purposes, and to return from emergency to regular operation, since the gas tube circuit is arranged to transfer automatically in only one direction.

The pilot supply circuit is shown in Fig. 5. The 3.9-kc. tuning fork oscillator at the left supplies that frequency, through the three transformers, to the three copper-oxide modulators the carriers of which are obtained from the regular channel carrier supply bus-bars as shown. The three filters, which are identical with channel carrier supply filters, select the lower sidebands to be used for pilot frequencies at 64.1, 92.1 and 104.1 kc. The three pilot frequencies are distributed to the different systems through protective resistances from a bus-bar as shown. They are set 100 cycles off the carrier frequencies to obtain locations of minimum interference from carrier leak and other sources.

Signaling circuits do not form an integral part of the carrier terminal equipment. Signaling equipment of a type already widely used in the Bell System for toll circuits, is connected between the toll switchboard and the four-wire terminating set of the individual channel.

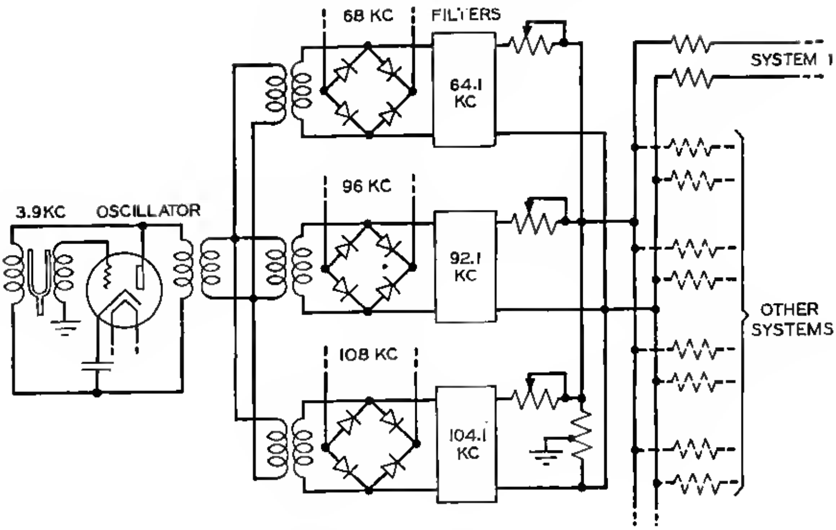

Fig. 5—Pilot supply circuit.

Transmission Performance

In general, the performance requirements set down as objectives in the development of this system were based on the assumption that five carrier links operating in tandem and over a 4000-mile circuit should give satisfactory, high-grade service.

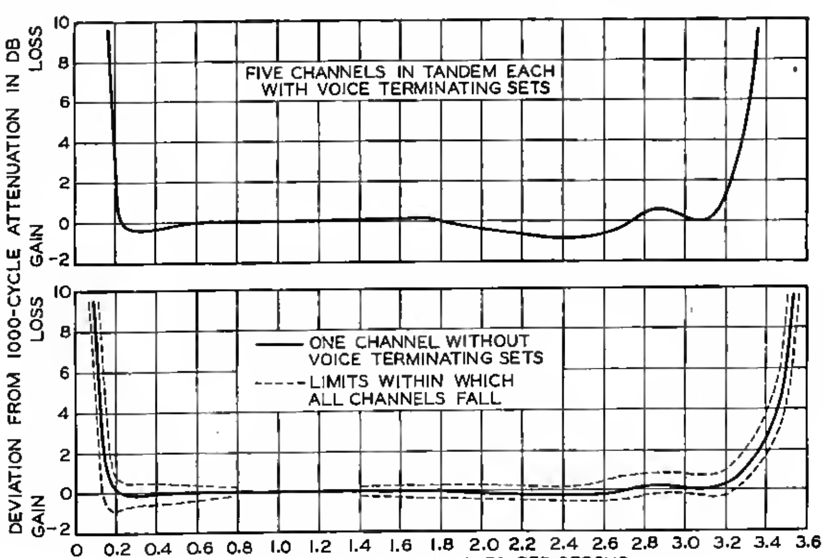

Fig. 6—Channel frequency characteristics.

The channel frequency characteristic which has been attained in the terminals is shown in Fig. 6. The solid curve below shows the frequency characteristic of a representative channel, while the dotted curves near it show the limits within which the characteristics of all single channels, so far measured, would fall. Above in the figure is shown the characteristic of five representative channels in tandem, each channel having its two voice terminating circuits included.

The delay distortion and time of transmission, contributed by all terminal apparatus at both ends of a system except voice terminating sets, are shown in Fig. 7 for a single channel.

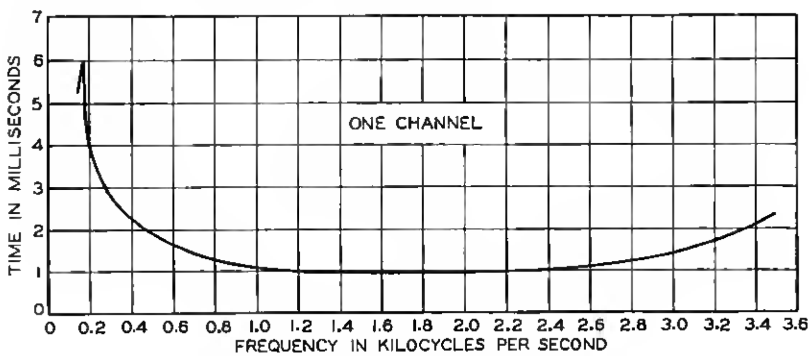

Fig. 7—Delay characteristic.

The channel modulators have been adjusted so that they will cut off the peaks of excessively loud talk to prevent overloading the carrier repeaters or other parts of the circuit, but this cutting is not enough to degrade the quality of speech. The single-frequency load curve of one complete channel is plotted in two ways in Fig. 8.

The frequency stability of the oscillating tuning forks is expected to be within $\pm 1 \times 10^{-6}$ parts per degree Fahrenheit on all systems, with negligible variations due to other causes. The amplitude stability of each frequency at its distributing bus is expected to be within $\pm$ 1/4 db over a period of months. The impedances of the bus-bars are sufficiently low so that crosstalk from one system into another through this path is unimportant. The effectiveness of the protective resistances at the carrier supply bus-bars is such that a short circuit on one modulator or demodulator will increase the loss in the remaining modulators and demodulators less than 1/2 db. The speed of switchover to emergency carrier supply is such that the disturbance to transmission will be less than 10 milliseconds. The effect on speech is not detectable.

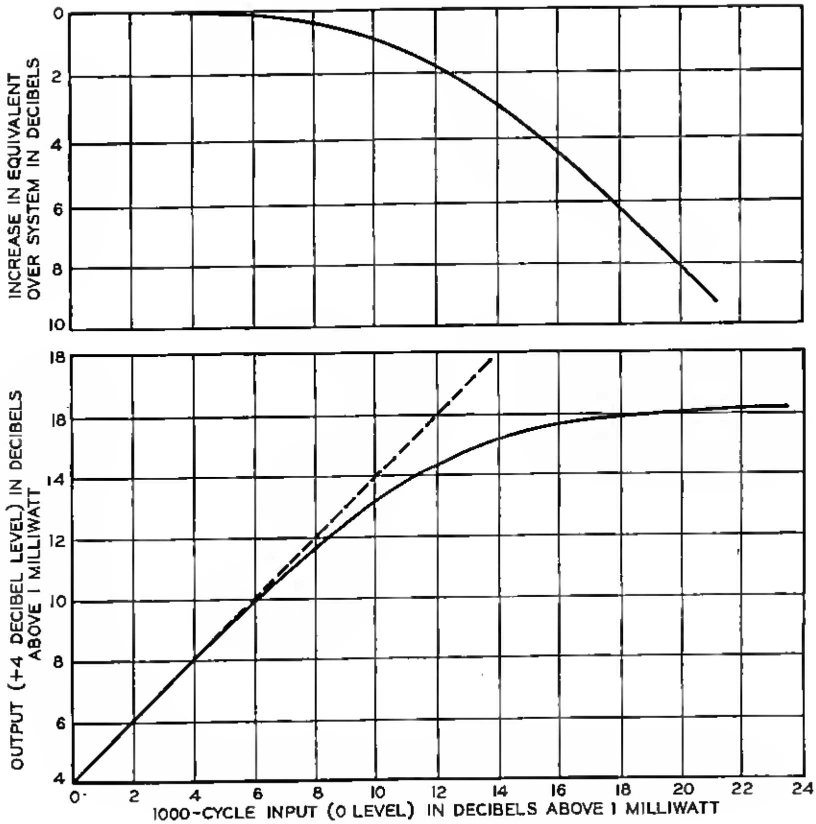

Fig. 8—Channel load curve at 1000 cycles.

Maintenance Features

Since the type "K" system provides more circuits in a group than ever before, it is essential that appropriately better maintenance facilities be furnished. Wherever vacuum tubes are used, jacks have been included to permit testing the condition of the tube by plugging in a new type of test set. The testing of a working tube with this set will not produce an appreciable reaction on performance of the circuits involved. When it has been determined that a tube in the common equipment is nearing the end of its useful life, a special transfer cord circuit is used to remove the circuit involving the tube from service and to substitute a spare circuit temporarily while the defective tube is replaced. This transfer from a regular to a spare and vice versa can be made without effect upon service.

In a type K terminal office transmission tests are made at the four-wire test board shown in Fig. 9, *A*, where the incoming and outgoing voice-frequency circuits appear, and at the high-frequency test board shown in Fig. 9, *B*. At the former, four-wire talking, monitoring and testing circuits have been provided for voice-frequency maintenance.

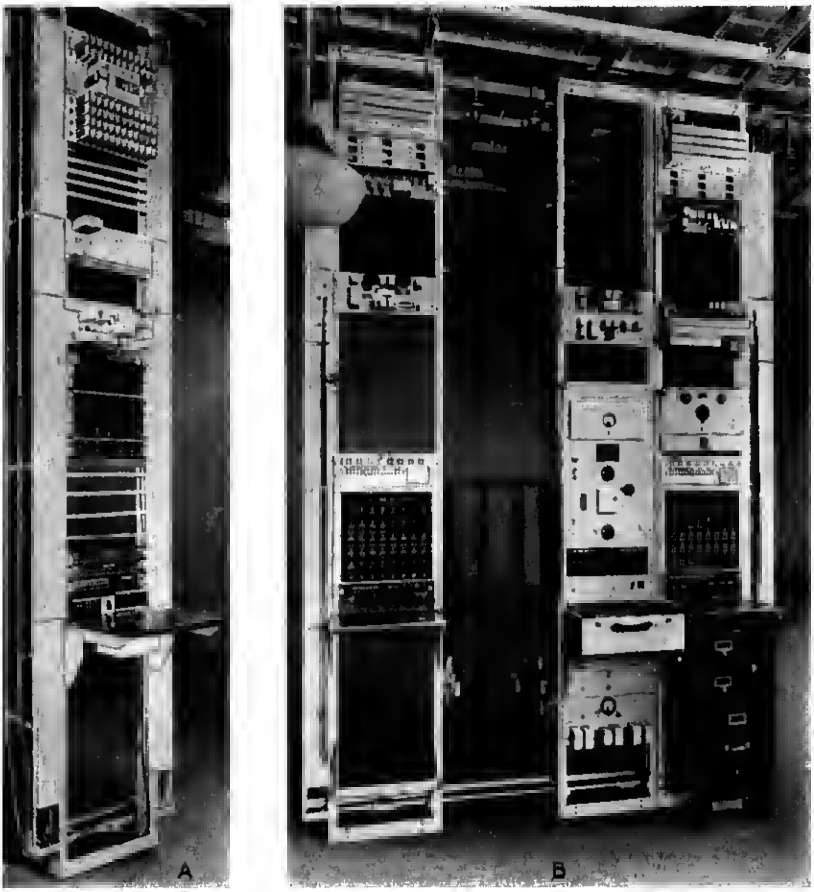

Fig. 9—Test positions: "A"—voice frequency; "B"—high frequency.

Adjustment of the equivalents of the individual channels can be made from this point as previously described. Much can be done from this position by means of monitoring and noise measuring to diagnose troubles.

At the high-frequency testboard the circuits are brought through jacks and high-frequency measuring apparatus is provided. Measure-

ments can be made on operating systems to determine the performance of the intermediate repeaters and regulators with respect to level and equalization over the frequency range from 12 to 60 kilocycles. Loss and gain measurements also can be made either between this point and the voice-frequency four-wire test board, through the carrier terminal equipment or through the next adjacent repeater or terminal office at high frequencies. It is possible to test the high-frequency portion of the terminal and to substitute a spare, by patching or rapid transfer, for a defective or potentially defective group modulator, transmitting amplifier, group demodulator or receiving amplifier.

Some of the high-frequency testing equipment is shown mounted on the middle bay of Fig. 9, *B*, of which one of the most important units is the 1 to 150-kc. test oscillator located at the center of this bay. It is a heterodyne type of oscillator which covers the frequency range with a continuous film strip scale about 300 inches long. Its maximum output is about one watt and this varies less than 1 db over the entire range. It is provided with built-in calibrating features and can be set to any frequency with an absolute accuracy of about 25 cycles. It is used as the tuning control of the pilot level measuring circuit. An auxiliary scale on the oscillator permits tuning the measuring circuit directly in terms of frequency.

The pilot level measuring circuit is of the double heterodyne type and includes a copper-oxide modulator which is supplied with carrier from the heterodyne oscillator, an intermediate frequency 130-kc. crystal filter of 10 cycles band width, a high-frequency amplifier for this frequency, a copper-oxide demodulator supplied with carrier from a 129-kc. fixed frequency oscillator, a voice-frequency amplifier and calibrating circuit. The input impedance of the measuring circuit is high so that when it is bridged across a line pair at the high-frequency testboard jack fields it does not produce appreciable loss to the line. The circuit permits measuring each of the three pilot frequencies to check levels and equalization of operating systems. The panels comprising the circuit are shown below the oscillator in Fig. 9, *B*.

Mounted on a shelf just below the oscillator is the transmission measuring set, which contains a highly accurate thermocouple and meter combination with calibrating circuits, wide range repeating coils, a test key circuit, and attenuators, one of which can be set in steps of 1 db up to a total of 90 db.

Equipment Features

Because of the large number of systems likely to be terminated in an office, the jacks are concentrated in a group of bays located together

for ease in patching and testing. There are in general five major divisions of the terminal equipment consisting of channel modem bays, group modem bays, carrier supply bays, high-frequency testboard, and four-wire voice-frequency patching board and associated voice termin-

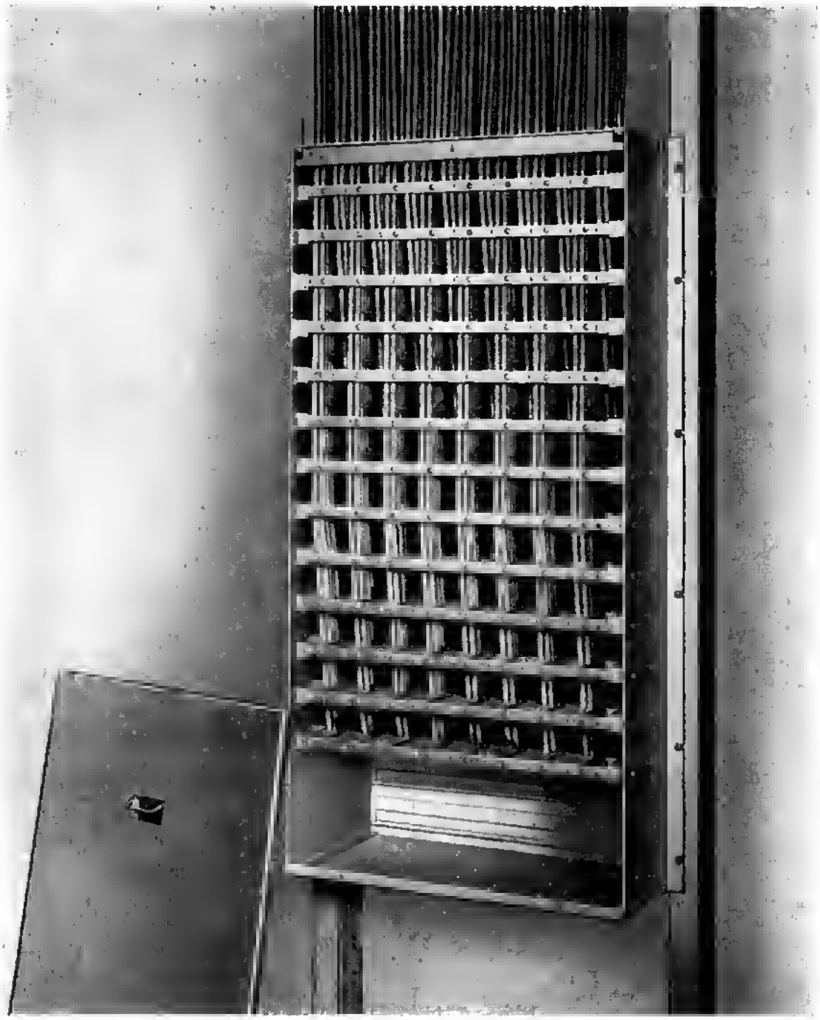

Fig. 10—Cabling of high-frequency jack bay.

ating equipment. The general arrangement in an office is such as to simplify the cabling between various groups of equipment

The cabling of a high-frequency jack bay, shown in Fig. 10, illustrates the congested wiring condition occurring when a large number of heavy

shielded wires is run to one location. Because of this congestion the jacks in this bay are mounted or removed from the front.

The concentration of equipment in the modem unit is made possible by the small size of the copper-oxide bridges and the filters. Fig. 11, *A*, shows twelve modem units for two systems on adjacent bays with space left at the bottom for the six modems of a third system.

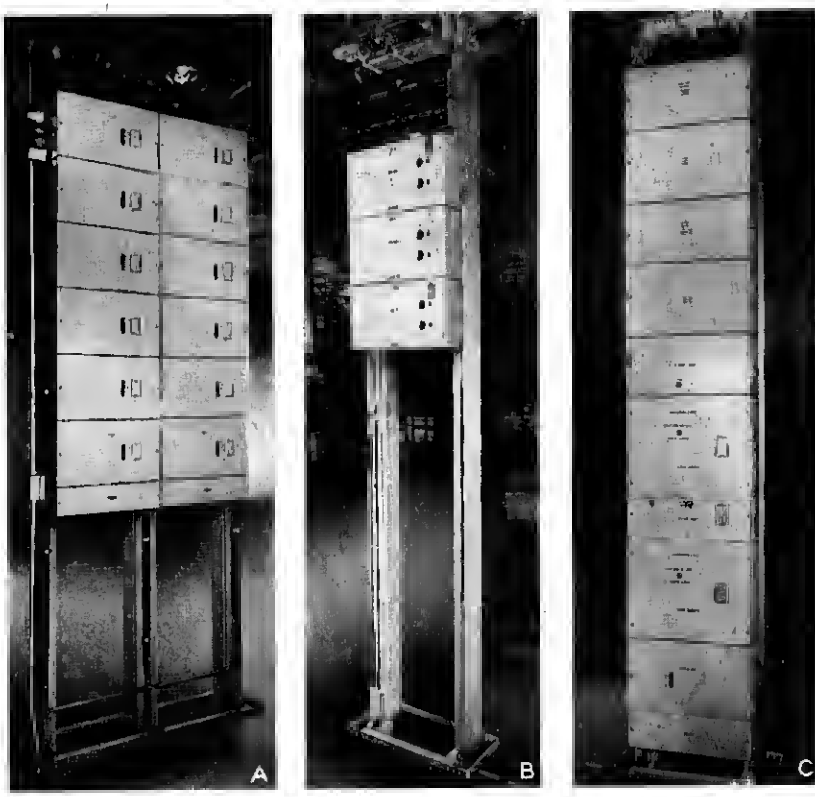

Fig. 11—Carrier equipment bays: "A"—channel; "B"—group; "C"—carrier and pilot supply.

The group modems are about the same size as the channel modems and include a modulator, a demodulator, a transmitting amplifier, and auxiliary receiving amplifier with associated filters. Fig. 11, *B*, shows three units for three systems with space for six additional units at the bottom of the bay.

The carrier supply equipment for ten systems is mounted in one bay as shown in Fig. 11, *C*, which includes the regular and emergency generators, transfer unit, distributing equipment and pilot channel supply

panel. The bays of this type are located near their associated channel equipment because the supply is chiefly for channel modems. One carrier distributing unit provides for the even and another for the odd harmonics. All terminals and bus bars of these units which are common to the ten systems are protected by insulating covers.

The four-wire voice-frequency jacks for all the systems in an office will ordinarily be grouped in associated bays, one of which is shown on Fig. 9, *A*. A bay will accommodate five systems as an average, that is, 60 voice circuits including the necessary pads and telephone set.

The high-frequency testboard is an arrangement of sealed test terminals, high-frequency patching jacks and high-frequency testing equipment mounted on bays as shown in Fig. 9, *B*. Only a few high-frequency patching jacks were required initially and these were therefore mounted above the sealed terminals. This arrangement of bays with the addition of a high-frequency patching bay at the right of each sealed terminal bay will accommodate 100 systems.

The carrier pairs are split off from the main toll cables at splices in the cable vault. The input circuits are carried thence in lead covered cable to the cable crosstalk balancing bays and thence to the input sealed terminal. The output pairs run directly from the output sealed test terminal to the splice in the cable vault. The remaining high-frequency wiring from rack to rack is shielded wire.

Conclusion

The carrier telephone terminals for the type "K" system which have been described are simpler, occupy less space and provide better transmission performance than multi-channel carrier terminals used previously in the Bell System. As part of a general development of broad-band transmission systems, it is very desirable to employ equipment which can be used in common with several systems. The 12-channel bay, much of the carrier supply and all of the voice-frequency terminating equipment of this type "K" system terminal will be used to form corresponding parts of the terminals for the 12-channel open-wire system and the coaxial system, both of which are under development. This not only has simplified the development work, but also will result in greater mass production of these common parts and provide desired uniformity of voice-frequency terminating levels and maintenance arrangements.

References

1. "Carrier Current Communication on Submarine Cables," H. W. Hitchcock, *Jour. of A. I. E. E.*, October 1926; *Bell Sys. Tech. Jour.*, October 1926.

2. "New Key West-Havana Carrier Telephone Cable," H. A. Affel, W. S. Gorton and R. W. Chesnut, *Bell Sys. Tech. Jour.*, April 1932.
3. "Carrier Telephone Systems for Toll Cables," C. W. Green and E. I. Green. Presented at the 1938 Winter Convention of the A. I. E. E. Published in this issue of the *Bell System Technical Journal.*
4. "Crystal Channel Filters for the Cable Carrier System," C. E. Lane. Presented at the 1938 Winter Convention of the A. I. E. E. Published in this issue of the *Bell System Technical Journal.*
5. "Magnetic Generation of a Group of Harmonics," E. Peterson, J. M. Manley and L. R. Wrathall, *Electrical Engineering*, August 1937.